Energy Reconstruction in KamLAND

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KamLAND is a scintillating detector. It is composed of a steel sphere with an 18m diameter that contains a balloon filled with a mineral oil pseudo-cumene mixture which scintillates surrounded by a layer of plain mineral oil that does not. The sphere is instrumented with 1325 seventeen inch photo-multiplier tubes (PMTs) and 554 twenty inch photo-multiplier tubes. Charged particles and gamma rays produce scintillation light in the balloon that is then absorbed and remitted at a longer wavelengths for the PMTs to detect. The time and charge of the photo-electron hits recorded by each PMT is used to reconstruct the original particles position and energy.

The current algorithm to reconstruct energy deposited in the detector looks at the total charge accumulated by the PMTs during the event and the position reconstructed from the time distribution of the event. An estimate of the amount of charge acquired due to accidental firing of the PMT is made by looking at a window before and after the event. The total charge is adjusted for this accidental charge and the parameterization of light transport through the scintillator then adjusts the energy until the total charge acquired agrees with the model. This algorithm reconstructs the energy of sources along the z-axis at the 1% level but the parameterization of light transport becomes unphysical at large radii causing a 2.2% deviation in the 2.2 MeV gamma ray from the capture of spallation neutrons near the balloon. Another problem arises due to errors in the accidental hit rate estimate. The window after the event still contains late light from the event therefore the estimate is too high. This causes some events to reconstruct with negative energies and causes errors in the energy scale below 2 MeV when the accidental hit rate becomes comparable to the hit rate from the physics event. The final problem is that the algorithm does not include the twenty inch PMTs so the energy resolution is not as good as it could be.

A new algorithm has now been included in the analysis to try to address these problems. The new algorithm uses a maximum likelihood fit to find the energy. The maximum likelihood is defined as the sum over the likelihood of each PMT being hit or not being hit in that particular event:

$$L(E,\vec{x}) = \prod_{i=1}^{1879} \begin{cases} 1-e^{-\mu_i} & \text{if hit} \\ e^{-\mu_i} & \text{if not hit} \end{cases} \tag{1}$$

where μ_i is the expected number of photo-electrons for that PMT. The expected number of photo-electrons is the sum of the number of accidental photo-electrons δ_i and the number expected for that energy at that position:

$$\mu_i(E,\vec{x}) = \eta_i \frac{\frac{\Omega(r,\theta)}{4\pi} e^{-r/\Lambda}}{\frac{\Omega(r_{center},\theta_{center})}{4\pi} e^{-r_{center}/\Lambda}} * E + \delta_i \tag{2}$$

where η_i is the number of photo-electrons per MeV at the center of the detector, Λ is the attenuation in both the scintillator and buffer oil, and Ω is the solid angle subtended by the PMT. The light transport model above is much simpler than the previous consisting of just the solid angle calculation and one exponential. The parameters that go into the fit, η_i and δ_i are extracted from ^{60}Co in the center of the detector.

The new algorithm can reconstruct the 2.2 MeV gamma ray from the capture of spallation neutrons at the balloon edge with only 1% deviation, figure 1 while continuing to reconstruct sources along the z-axis at the 1% level. The inclusion of the twenty inch PMTs gives improves the energy resolution from 7.5% to 6.5% and taking the accidental hit rate, δ_i from a window before ^{60}Co events has removed the negative energy events. Unfortunately, the timing distribution from ^{60}Co is different than that for physics events and is causing a dark rate estimation that is a few percent too high which leads to a similar problem in the energy scale below 2 MeV since there the accidental hit rate becomes comparable to the physics hit rate. Since the reactor neutrino analysis threshold is at 2.6 MeV this is not a problem but for the geo-neutrino analysis with a threshold at 0.9 MeV this is a problem that needs to be solved.

A recent trigger upgrade has implemented random triggers at 1 Hz to study the accidental hit rate. This data then can be used to tune the algorithm which extracts the accidental hit rate from ^{60}Co and should fix the energy scale problem. The new algorithm is also neglecting shadowing due to the ropes that hold the balloon and other objects in the detector. This causes structure in the energy reconstruction along the z-axis. The next version of the algorithm will use a Monte Carlo integration to account for these effects. These two upgrades should fix the outstanding energy reconstruction problems.

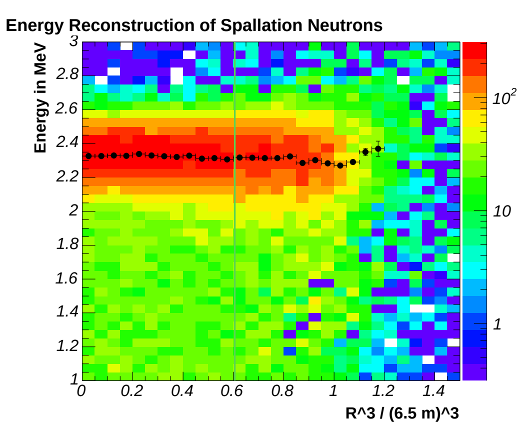

FIG. 1: Energy Reconstruction as a Function of R.